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# Planetary systems in star clusters

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**Abstract.** In the solar neighborhood, where the typical relaxation timescale is larger than the cosmic age, at least 10% to 15% of Sun-like stars have planetary systems with Jupiter-mass planets. In contrast, dense star clusters, characterized by frequent close encounters, have been found to host very few planets. We carry out numerical simulations with different initial conditions to investigate the dynamical stability of planetary systems in star cluster environments.

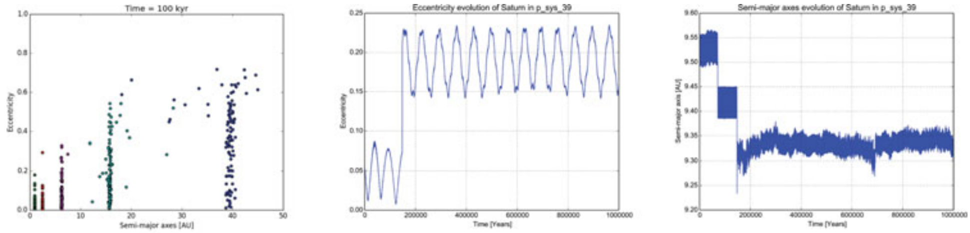
**Keywords.** planetary system, star cluster, stability, free-floating planets

## 1. Introduction

Recent studies suggest that most stars are formed in groups and clusters (Lada & Lada 2003). The evolution of star clusters is driven by internal (e.g. two-body relaxation, mass loss by stellar evolution), as well as external processes (e.g. tidal forces of a galaxy) (Spitzer 1987, Elson *et al.* 1987). Since these mechanisms finally lead to the dissolution of clusters they have a finite life time. So, if our sun has been born in an open star cluster, the solar planetary system may also have formed before the dissolution of its parent star cluster.

Observations of exoplanets have been possible since the early 1990s. As of December 2014, more than 1,800 exoplanets have been discovered, among which are 473 multi-planet systems like our own solar system (`http://exoplanet.eu`). Nevertheless, most exoplanets are found in the solar neighborhood; very few exoplanets (e.g. Kepler-66, Kepler-67) are found in star clusters. Star clusters, especially cores of globular clusters, are characterized by high density of stars and high velocity dispersions, which results in frequent close encounters. Current observations suggest that planetary systems in dense regions of star clusters have difficulties to maintain their orbital stability. This could be due to instability against external gravitational perturbations, though there may also be some instrumental biases due to detection limits.

Previous studies include direct $N$-body simulation (Spurzem *et al.* 2009) and Monte-Carlo simulations (Hao *et al.* 2013). We present numerical simulations to investigate the dynamical stability of planetary systems in star clusters. Coupling planetary system with star cluster dynamics is a multi-scale problem, due to time scales ranging from $\sim 1-100$ years for planetary orbits to $\sim 10^4-10^6$ years for stars orbiting in the cluster. Full direct coupled simulations are expensive, though not impossible (see e.g. Spurzem *et al.* 2009); but frequently Monte Carlo approaches are used (see e.g. Hao *et al.* 2013). The `AMUSE` framework is a convenient toolbox to study such a problem (Portegies Zwart *et al.*, 2013; Portegies Zwart *et al.*, 2009). Within `AMUSE` we integrate star cluster dynamics directly with `NBODY6++` (Spurzem 1999), while the planets are integrated with `MERCURY6`




(a) (b) (c)

**Figure 1.** (a) Diffusion of the $a-e$ space at $t = 100$ kyr of a simulation; (b) Eccentricity evolution of Saturn in one of the planetary systems; (c) Corresponding semi-major axis evolution of Saturn in the same planetary system as (b).

(Chambers 1999). The perturbations are implemented with the `BRIDGE` scheme (Fujii *et al.*, 2007; Pelupessy *et al.*. 2013). All coupling is done within `AMUSE` framework.

## 2. Results and conclusions

For the initial setup of our system we follow the previously cited papers (Plummer sphere for stellar density, $N = 2$k and $N = 10$k stars, virial radius $R_v = 1$ pc; (A) current gas giant configuration or (B) equal mass and mutual Hill radii separation for the planets). For case (B) the inner planet has $M = 1M_J$ and $a = 1$ AU. We distribute 50 (100) planetary systems randomly across the $N = 2$k ($N = 10$k) cluster, to sample different positions and environments of planetary systems in star clusters.

Figure 1a shows the $a - e$ space (semi-major axis verses eccentricity) at the end of the $N = 10$k simulation (corresponding to $T = 0.1$ Myr). The evolution of semi-major axes and eccentricities of Saturn in the $N = 2$k simulation are shown in Figures 1b and 1c, respectively. Our simulations show that generally planetary systems have difficulty surviving within dense cluster environments, but some compact ones are sheltered in the potential well of their hosts from disruption.

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